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IMAGE ANALYSIS APPLIED TO FIBRE IMAGES

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Abstract

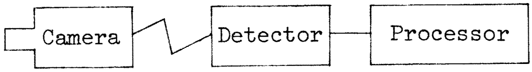
In this paper we present a historical review of the development of image analysis hardware and describe the types of equipment which are commercially available today. We also discuss probable future trends in the development of automatic image analysis systems. Against this background the problems specific to analysing images of fibres are described and illustrated by experimental results obtained working with phase contrast microscope images of asbestos fibres.

Image Analysis Systems

Since their introduction nearly two decades ago automated image analysis systems have undergone many important changes. These have been made possible by changes in electronic and computer technology. Most systems are based on standard or special format TV input whilst many offer interfaces to other types of input device. For the purposes of this discussion we shall confine ourselves to these TV based systems.

1. Non-programmable systems

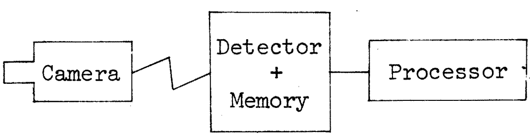
The first commercially available systems were non-programmable with hard-wired electronics to perform the repertoire of the instrument.



The main elements of such a system are the camera, a detector to transform the input image into a binary image, and a processor to make measurements on the detected image. The detector in such systems usually uses grey level thresholding or some variant of it. Points in the image (pixels) are classified as belonging to `object´ or `background´ based on whether their brightness lies between or outside pre-selected limits. These limits or thresholds are normally set up interactively by adjusting controls on the instrument. The detected image is processed by a computer which can calculate parameters such as the area of the image which has been detected, while later developments increase the instruments´ ability to make measurements of individual objects. The processor must work at very high speed with data presented in TV format and it only proves feasible to design a system with a limited repertoire of measurement functions, switch selectable from the instrument controls.

2. Semi-programmable systems

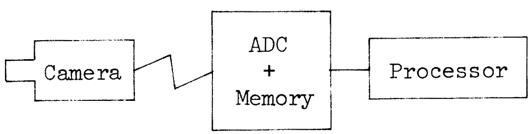
With the introduction of small, cheap programmable computers, there was an obvious simplification that could be made to image analysis systems, introducing a greater degree of flexibility.



Although a programmable processor could not cope with data directly at the rate it is produced by a video rate detector, a simple interface can be achieved by the addition of a memory which can store for each pixel the result of a thresholding decision. In such a system the detection unit is still a hard-wired unit, normally with manual controls, but the processor is completely programmable allowing the same piece of hardware to perform different measurements on the detected image merely by changing its programme. The processor, which is often a proprietary mini-computer, can control access to data in the detection memory and by suitable logic involving the connectedness of detected points can, in principle, make any measurement involving the size, shape or relative positions of objects in the image. Such a system is, however, still only semi-programmable since the initial transformation from continuous tone to binary image is performed in a fixed way by a hard-wired unit.

3. Fully programmable systems

The possibility of fully programmable image analysis systems came with the developments in electronics which allowed very high speed computers and large memories at reasonable cost.



In such a system the hard-wired detector is replaced with an Analogue to Digital Converter (ADC) which converts the brightness of each pixel into a number. Typically, a six bit number would be used, giving a brightness value in the range 0 - 63. As in the semi-programmable systems a processor could not cope with the data directly at video rates and so it is necessary to have an intermediate store, this time for brightness values. In such systems the process of detection can be programmed and it is thus possible to use more sophisticated methods than grey level thresholding. This is of major importance since it turns out that the detection phase of analysis is often the most crucial and that for any but the most simple samples grey level thresholding is unsatisfactory.

Since the processor in a fully programmable system is doing much more work (detection in addition to measurement) its performance needs to be greatly enhanced. It is not a practical proposition to use a standard mini-computer and a system with purpose-designed architecture must be employed.

4. Systems on the market

There are examples of each of the types of instrument which we have discussed on the market today. Non-programmable systems can still be of value where the images and measurements required are very simple. In these circumstances the lack of flexibility is unimportant and cost can be minimised. It seems likely that semi-programmable systems will be soon superceded since they differ from fully programmable systems primarily only in the amount of memory required and in the architecture of the processor. Large memories and processors of advanced architecture can now be manufactured at sufficiently low cost to leave little advantage in an intermediate system. Fully programmable systems with whole image stores are now available from several manufacturers, whilst suppliers of computer display systems are beginning to approach the same market from a different direction. The important distinctions which must be made between such systems will be in the suitability of the architecture and in the provision of standard software libraries for image analysis. All must be capable of `cosmetic´ image processing and sophisticated graphical representation of results.

Analysis of Fibre Images

In common with many applications of image analysis the processing of images containing fibres can be broken down into three main stages. First the material of interest must be DETECTED, next its structure must be ANALYSED (in this case to separate out individual fibres), and finally variables of interest must be MEASURED. Each of these tasks present particular difficulties which arise from the nature of fibre images.

1. Detecting fibres

The first stage of analysing a scene containing fibres is to detect all the fibrous material present. Fibres, by definition, are structures with high length-to-breadth ratio and as a result are often viewed at a magnification where, in order to see complete fibres, the width is a very small fraction of the field of view. In these circumstances the apparent contrast of the fibres as seen by a TV camera or other image transducer can be very low so that the signal-to-noise ratio is poor. In other words the difference in detected brightness of a point on a fibre compared to background is not much larger than random fluctuations in background. The human visual system has no difficulty in recognising such low contrast fibres since it uses some sophisticated processing to correlate brightness information spatially in order to extract `line′ or `edge′ information. In our work on phase contrast microscope images of asbestos fibres we found it necessary to use such a correlation technique in order to achieve satisfactory detection of the fibrous material. The low signal-to-noise ratio renders grey level thresholding unsatisfactory, but a method involving linear correlations over a 5 x 5 pixel neighbourhood surrounding each point in the image has provided demonstrably improved results allowing fibres to be detected at several times lower contrast than would otherwise be possible.

2. Analysing Fibre Structure

Once the fibrous material in an image has been detected it is, for many applications, necessary to analyse the structure in order to separate out individual fibres. Because of the, normally, high length-to-breadth ratio of fibres it is very common for individual fibres to overlap each other: indeed, as in paper-making, this is often the intention. This means that the task of separating individual fibres is non-trivial and that special methods must be developed which make use of the known properties of the fibres. We have developed techniques for application to asbestos fibre images which involve simplification of the detected image followed by application of geometrical measurements of continuity.

Some simplification of the detected image is almost essential as a first stage in order to make the problem of separating overlapping fibres tractable. We have used a method called skeletonisation where the width of the detected structures is successively reduced so long as this can be done without altering the degree of connectedness. This results in a representation of the fibres by lines of unit width. As a second stage of simplification all junctions between these idealised fibres are removed leaving a set of simple segments each with two free ends.

Given this simplified representation it is now possible to consider the continuity represented by different pairs of potentially matching segments and to construct a `best fit´ to the original fibres by associating segments together to form complete fibres.

3. Measuring Length and Width

Once the path of each individual fibre has been found and represented by a sequence of simple segments, measurements of fibre length and width may be made. Length can quite sensibly be defined as the distance travelled in tracing the complete path of a fibre along its successive constituent segments. It should be noted that in fact care must be taken to correct for some of the unwanted effects of skeletonisation.

The measurement of width is more problematic. For asbestos images we have adopted a method which uses brightness profiles taken at many parts along the fibres always in a direction perpendicular to the local tangent to the fibre skeleton. The reason for using brightness information is that measuring width simply from the detected image would be too crude, since fibres are rarely more than a few pixels wide and width measured in this way would always be an integral number of pixels. Using brightness information it is possible to interpolate between pixels and obtain a more continuous measurement of width.

Once the width has been measured in a number of places, it is necessary to apply some logic to the values obtained, since some may have been made where fibres crossed and thus be in error. The method which we have used is to look for groups of similar measurements, rejecting uncharacteristically extreme values.

Discussion

We have described some of the types of hardware which can be used for image analysis and have discussed some of the problems particularly associated with fibre images. The algorithms which we have described for solving these problems are of sufficient sophistication to require a fully programmable system where grey level manipulations may be performed at high speed. We have implemented these methods on the Vickers MAGISCAN system though there are several recently introduced systems which may also be suitable.

The properties of the asbestos fibre images with which we have been mainly concerned are probably similar, though not identical, to those of paper fibres, though clearly a higher degree of overlap may be expected. Certainly there is no obvious reason why the method which we have developed should not be applied to paper. It is however probable that there may be other problems specific to paper fibre images that will also need solving. Generally it is possible to conclude that although some simple and useful measurements might be made with a non-programmable system it will, in general, be necessary to use fully programmable image analysis systems in order to extract any detailed information from paper fibre images.

Discussion

Panel Discussion following papers presented by Dr. Jordan, Prof. Kropholler and Dr. Taylor.

Dr. B. Jordan

I have a question for Prof. Kropholler. Several years ago Rosenfeld[1] published a note in which he claimed that if one worked with Fourier transforms locally in texture analysis then the edge effects were so pronounced that it made the Fourier or power spectrum useless as a local image-segmenting technique. Hence he favoured run-length statistics. Do you agree with this?

Prof. H. Kropholler

I agree with the comments that you just made. We are not seriously using Fourier techniques, in texture analysis.

Dr. L. Eriksson, STFI, Sweden

I have a question regarding sample preparation. Fibres are three-dimensional in terms of curl. Presumably during analysis the fibres are stationary and thus restrained in some way by external forces. How is sample preparation carried out so as to reflect the true curl?

Dr. B. Jordan

We use a projection technique. There is the underlying assumption that a fibre with say, helical structure is not straightened by squashing it down onto a plane, it will maintain curliness. A straight fibre on the other hand will remain straight on projection.

Mr. B. Klowak, American Can Corporation, Wisconsin, USA

I understand that Dr. Jordan used a proportionality with length to estimate fibre weight. I would like to ask why he did not use a proportionality to area?

Dr. B. Jordan

That is a good question. Actually we have used both methods and there is no great difference.

We have also used, as I mentioned, a method where we take a calibration curve of weight as a function of length.

Mr. B. Radvan, Wiggins Teape, UK

Dr. Jordan, the histograms of radii of curvature which appear in your contribution always had a high population at low radii which you have ascribed to kinks. Do you think this could be used as a measure of damage to the fibres?

Dr. B. Jordan

Yes. There is a great deal of information in these histograms and what we have to do is to find appropriate weights between the high frequency and the low frequency contributions to try to extract something meaningful. Obviously, there is added information if you used both the curvature and the curl. The question remains: what is the paper-making significance of the added information, and is it worth the extra effort? This is the subject of our activities at present.

Dr. C. J. Taylor

We also use curvature measurements similar to those described by Dr. Jordan. We have found that this allows us to differentiate between asbestos and other types of fibres by using syntactic analysis of the resulting histograms.

Prof. K. I. Ebeling, Helsinki University of Technology, Finland

I would like to ask what resolution is possible with the technique. Could you for example analyse the effect of strain on bonded area response, particularly with respect to the effect on the centre area of a bond?

Dr. B. Jordan

The largest problem is one of getting an appropriate image. This is always a problem in image analysis.

I think we have enough contrast to look at local deformations at bond sites, but we have not done it at present.

Dr. M. B.Lyne, Paprican, Canada

Many people could be considering the purchase of an image analyser. It would be of interest to know what hardware is required with the analytical equipment that you have described today in order to guarantee inter- and intra-laboratory agreement. In particular, reproducibility of the detection criteria and sample illumination are required.

Dr. B. Jordan

For print quality applications, this is adequately discussed in our paper in Tappi(2).

Illumination is important for fibres also, though not as critical as one might suppose.

Dr. C. J. Taylor

There is generally a better chance of getting good agreement between different sites if the image analysis method used represents some physical model of the subject under consideration. In other words, sample-related techniques are likely to lead to a failure to agree. For example, specific effects or tricks are difficult to reproduce.

Prof. H. Krophollor

I would add that the problems of repoducibililty are even present within one laboratory. On texture-type problems it is imperative to have some calibrating sample included with the samples. Work on fibres can be easier since dyeing the fibre can often result in enough contrast. The physical characteristics that one is looking for can be simpler.

Dr. C.J. Taylor

With some types of image grey-level thresholding can be applicable to asbestos fibres. The problem with this technique is that it is totally variable and different answers are obtained on different occasions since even automatically self-adjusting systems have considerable arbitrariness.

The model we have used supposes a consistently lower optical density related in a linear fashion and a measurement of that is made. The results on the final count don't alter under an order of magnitude change in the illumination on the slide.

Dr. B. Jordan

In situations where the signal – to-noise ratio is very critical then the precise grey-level threshold can be very important. However, in most situations a response plateau is reached, and large changes of illumination are possible without any significant effect on the results.

Dr. C. J. Taylor

Certainly in our experience edges are rarely sharp enough in microscope images and I would have expected that a change in threshold would be expected to give a significant change in the fibre width that you observe.

Dr. B. Jordan

This can be a problem, but the threshold setting that we use is the mid-point of the edge and thus symmetrical broadening from whatever cause, such as the optics, will not have much effect. We have, to date, found reasonable reproducibility over many samples.

Mr. A. de Ruvo, STFI, Sweden

What kind of TV camera is recommended for use on printability studies, where grey-scale measurements are all important.

Dr. C. J. Taylor

We always use a Chalnicon tube because in practice all other tubes are fragile. It has high resolution on near-linear intensity response, and good sensitivity. If you are interested in looking at complete images with a wide intensity range, and you need information from the low intensity areas without saturating the high areas, then a Vidicon with $\gamma = 0.7$, whose response slopes off at high levels, might be more appropriate.

Prof. P. Luner, ESPRI, USA

Returning to the question of the move away from using Fourier transforms to describe structure, is there any problem with the type of signal and its processing or does the problem lie in the paucity of information gained?

Dr. B. Jordan

The computational demands for handling the grey-level occurrence matrices and other real space statistics are just as large as for the Fourier transform. The problem with the Fourier transform lies in its local application and in the presence of edge effects. The finite Fourier transform assumes that the signal is reproduced over and over again outside the sampling region. This small sampling causes errors, as pointed out by Rosenfeld.

Dr. C. J. Taylor

From our experience of using Fourier methods, even when they are not applied locally, the Fourier transform of anything looks much like the Fourier transform of anything else.

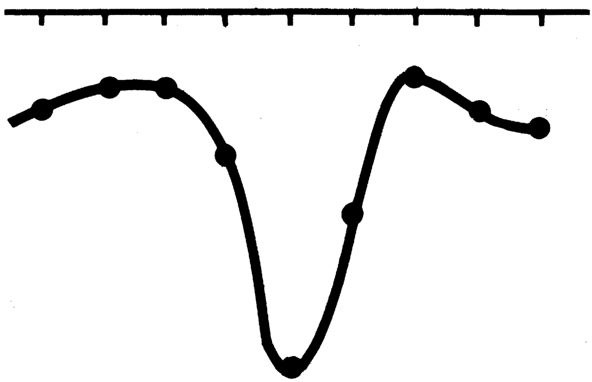
Fourier has some nice properties, for example, it is not dependent on translation, and orientation can be removed. Unfortunately, it tends to mask phenomena which human observers see.

Dr. F. El-Hosseiny, Weyerhaeuser, USA

A few years ago I was trying to measure the radii and diameters of textile fibres and I found that there was an observable change with a change in refractive index of the immersion fluid. The difference was very high particularly when trying to measure small objects. I would like to draw attention to this fact as it might not be well known.

Dr. C. J. Taylor

This problem can be extreme with asbestos fibres which are at the limit of resolution of the optical microscope. We use phase contrast images and so the image looks as shown below.



The question that then arises is whether any one pixel forms part of the fibre image or not. We look at the intensity values of the individual cells and fit a curve through these points. If we know the response function of the microscope then a proper measurement of width can be derived though the arguments are complex.

Dr. B. Jordan

This is a serious problem with phase-contrast work. The transfer function of phase-contrast is asymmetric.

Dr. C. J. Taylor

This is true, I was, of course, just citing one example. The main point is that at high magnification it is important to take account of the microscope optical transfer function during the measurement and analysis phases.

Dr. B. Jordan

One can generalise this by saying that one must be very careful with the optics of the image. It is like the old computer saying "garbage-in:garbage-out". If you have poor quality images or if you are working at the limit of your optics then this has to be attended to: you are quite right.

Dr. R.P. Taylor

I believe you are using raster-scan, high-resolution image tubes. For images of fibres where there is a high length to diameter ratio would it be possible to use a non-raster type tube where a spot is made to follow an image under computer control? This may be a more efficient technique.

Dr. B. Jordan

Image dissector camera systems are available on the market which do just as you say: Lamont make one example.

Dr. C. J. Taylor

The problem is one of process speed. Devices which track images can only integrate photons from that one point. A raster system integrates photons for the whole of a frame. The time economics of raster-scan devices is superior to random-access devices.

If image storage were a problem then tracking devices may be used but this is not usually the case.

B. Attwood (Chairman)

This was a very interesting session and it could well provide the basis for an interesting one-or two-day seminar.

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